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An introduction to solar power electronics

Disclaimer: This article has been derived from the excellent work of Venkata R. et al written ,"State-of-the-art power electronics systems for solar-to-grid integration", published in the Elsevier journal Solar Energy,16 July 2020. The author has only reported.

Introduction

Power generated by photovoltaic (PV) panels is highly vulnerable to uncertain weather conditions, and impedance connected to its terminals. Therefore, to maximize the energy productivity from panels by controlling output impedance, a power electronic converter capable of adopting maximum power point tracking (MPPT) technique is required. Power processing equipment such as dc/dc converters and inverters are mandatory in extracting power from PV panels and utilizing either for standalone systems or grid integration. Grid integration is a major focus where access to utility line ranging from domestic micro-inverters (<300W) to solar generation (>MW). A centralized inverter topology interfaces a MW power rating PV farm consisting several parallel strings of series connected PV panels to the grid. Module configuration integrates power conversion stage directly to the PV modules. Depending on the type of power conversion, module configurations are classified into cascaded dc Module, parallel dc Module, ac module, and quasi-ac module as shown in Fig.1.

The solar PV power can either be delivered directly by injecting the power into the utility grid by solar-to-grid integration or by operating them in islanded mode to supply power to local loads in case of remote locations. It can also be used with other energy systems such as fuel cells and energy storage (batteries, supercapacitors, flywheels) to form a hybrid energy system (Xu et al., 2018). In all the cases, the power electronic converters play an important role to (1) extract maximum power from the PV panel to deliver to the load known as maximum power point tracking (MPPT) controller. (2) elevate the PV voltage to a required voltage level by a dc/dc converter and (3) convert in the ac form by a dc/ac inverter.

A major challenge in solar power system is to tackle its nonlinear current–voltage (I–V) characteristic, which results in a unique maximum power point (MPP) on its power – voltage (P–V) curve. The power generated from a given PV module mainly depends on solar insolation and panel temperature and vary with weather conditions. The variation of solar panel current and power with variation in solar irradiance. The panel voltage remains nearly constant; however, the panel current varies causing the change in power and so obviously the MPP. As the solar irradiance goes low, the panel current and power along with MPP goes down.

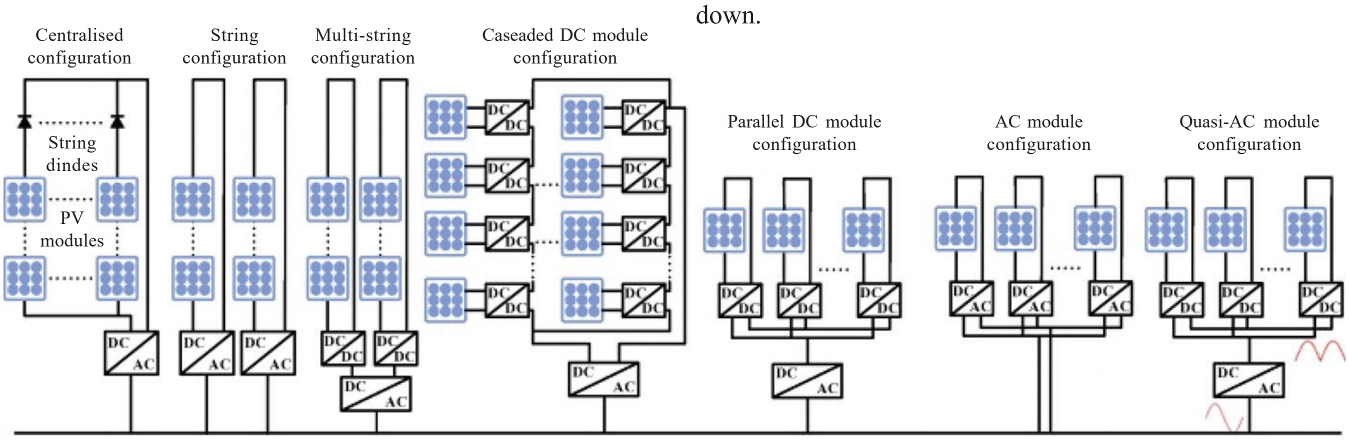

Fig.1: Different structures used in PV system

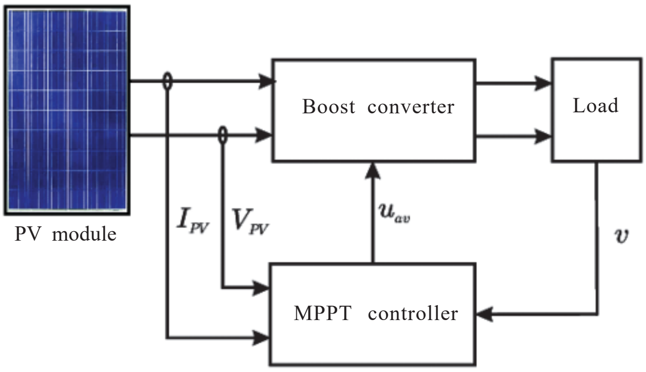

Fig.2: Solar integrated PV conversion system with MPPT

High-frequency (HF) dc/dc converters

Dc/dc converters are usually adopted for these module-integrated converter for dc module and quasi-ac module configurations as shown in Fig.1. Even for ac module configuration, additional dc/dc converter with HF isolation are widely used to interface low voltage PV modules. Therefore dc/dc converters play an essential role in both multistring and module configurations of PV systems.The overall requirements of dc/dc converters for PV systems are summarized as follows: (1) high voltage gain to elevate solar panel voltage; (2) low input ripple for better MPPT tracking; (3) high efficiency for faster return on investment; (4) low cost for system commercialization, (5) low volume for space consideration, and (6) long lifetime (matching 25 years of warranty with solar panels). Galvanic isolation is also preferred to reduce the ground leakage current. Dc/dc converters can be classified into two major types, voltage-fed and current-fed. The difference is that voltage-fed converter employs a large capacitor in parallel connection with the source while current-fed converter employs an inductor in series connection with the source. The HF isolated dc/dc converters for PV system applications have emerged as possible solution for the low cost, light weight, and low volume benefits. HF pulse width modulated (PWM) dc/dc converters and HF resonant converters are two mainstreams.

High-switching frequency operation

At low or moderate power levels, HF power converters are used to accomplish compact, lightweight and low cost system. The switching frequency may vary from 20 kHz (medium power) to 1 MHz (low power) based on the specifications. However, high-switching frequency operation of the semiconductor devices results in higher switching losses, thus limiting the power conversion efficiency. Therefore, soft-switching of the semiconductor is implemented to reduce the switching losses, thus realizing high efficiency. The soft-switching can be implemented using PWM techniques or resonant tank. Resonant tank suffers from the demerits of the complex variable switching frequency control and circulating through the components demanding overrated components. Also, optimizing the tank kVA rating or the resonant tank parameters is a challenge to optimize the efficiency and the volume. PWM techniques offer simple control but limited soft-switching range. If the source is variable like solar, then soft-switching range in PWM converters and switching frequency range in resonant converters, become a challenge. Voltage-fed converters suffer from high peak currents if a capacitive filter is used and suffer from duty cycle loss, voltage ringing and snubber requirements if inductive filter is used. On the contrary, current-fed converters offer voltage gain, short circuit protection, current limiting feature, and free from the problems of the duty cycle loss and voltage ringing. However, current-fed converters suffer from the hard device commutation resulting in high voltage spike across the devices at their turn-off. Therefore, auxiliary snubber or clamping circuit is usually required for current-fed converters. For power conditioning a higher power, owing to the unavailability of the higher blocking voltage semiconductor devices, multilevel converters are used. For better device utilization, limit the switching losses, and to limit the cooling requirements, device switching frequency is usually limited to <1 kHz and currently between 50Hz and 500Hz based on the power level. Multilevel converters suffer from the large number of capacitors and device requirements but reduced filtering and cooling requirements and therefore, used for high power generation.

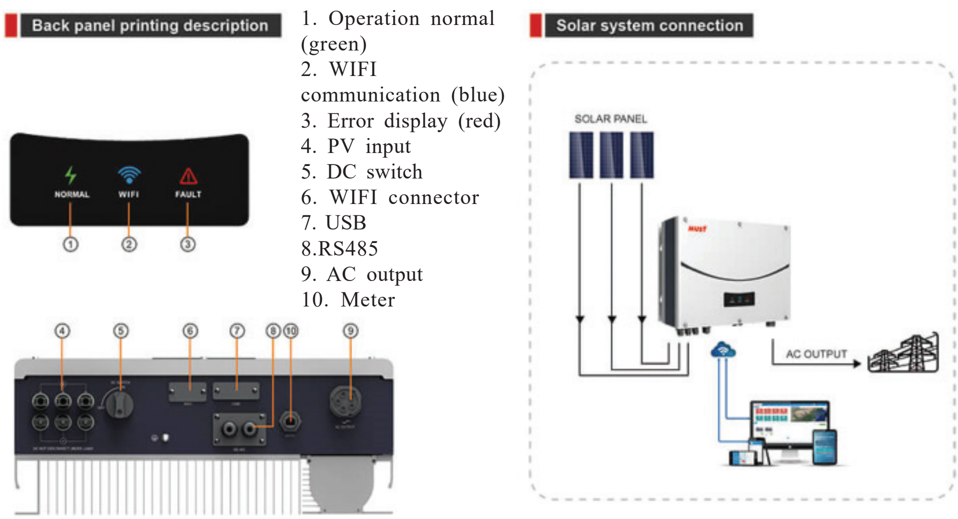

Fig.3: High frequency solar inverter high frequency on grid solar inverter